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Title: Determining x-ray spectra of radiographic sources with a Compton spectrometer

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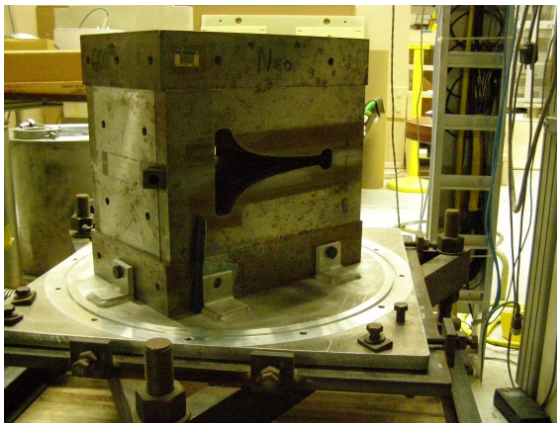
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Determining x-ray spectra of radiographic sources with a Compton spectrometer

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Acknowledgements

Collaborators:

- Michelle Espy
- Todd Haines
- James F. Hunter, Nick S. P. King, Manuel J. Manard, Frank E. Merrill, George L. Morgan, Robert Sedillo, Rusty Trainham, Algis V. Urbaitis, Petr Volegov

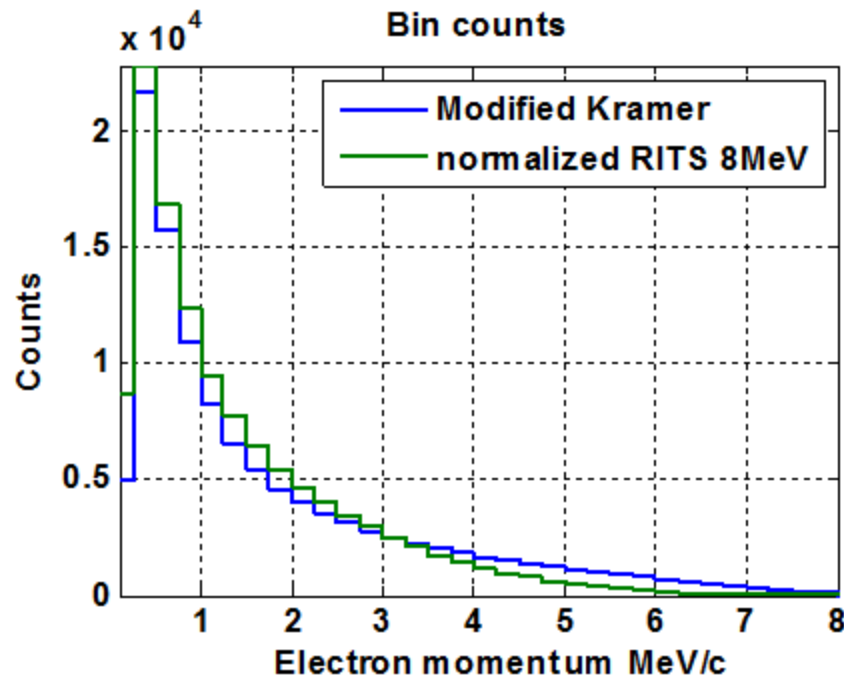
Special Thanks to:

- Calibration measurements preparation: Tom Keenan, Glen Anthony, and Ben Valencia
- Microtron operation: John Stearns
- ^{60}Co source operation: Samuel Gonzalez and Timothy Dugan
- Magnetic field map: David Barlow

The x-ray spectra of flash radiographic sources is difficult to measure

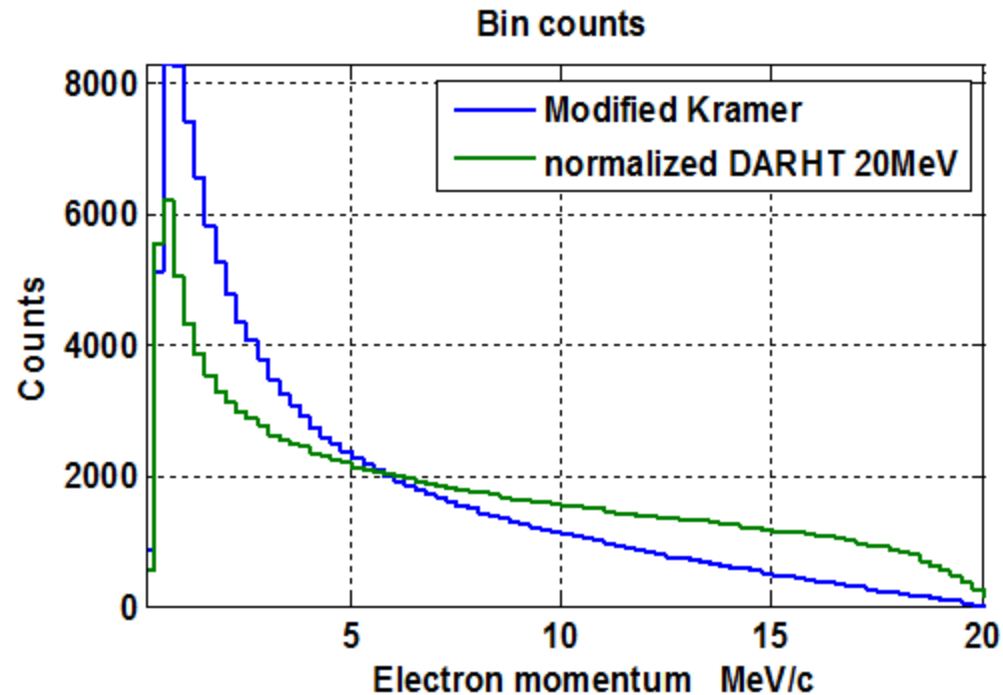
RITS-6

370 rad at 1 m; 50 ns pulse

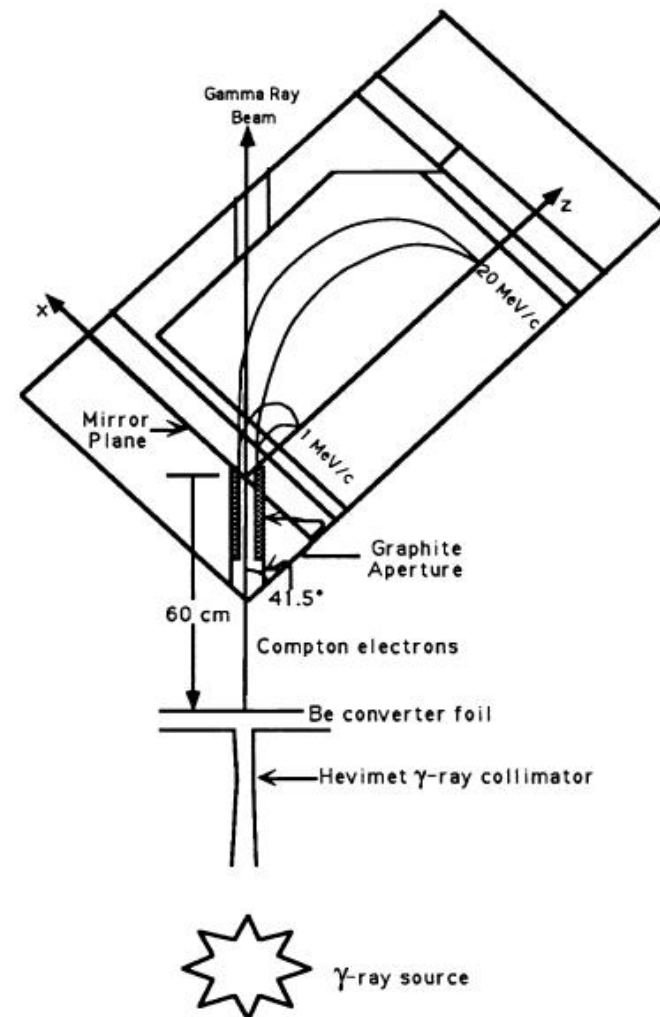
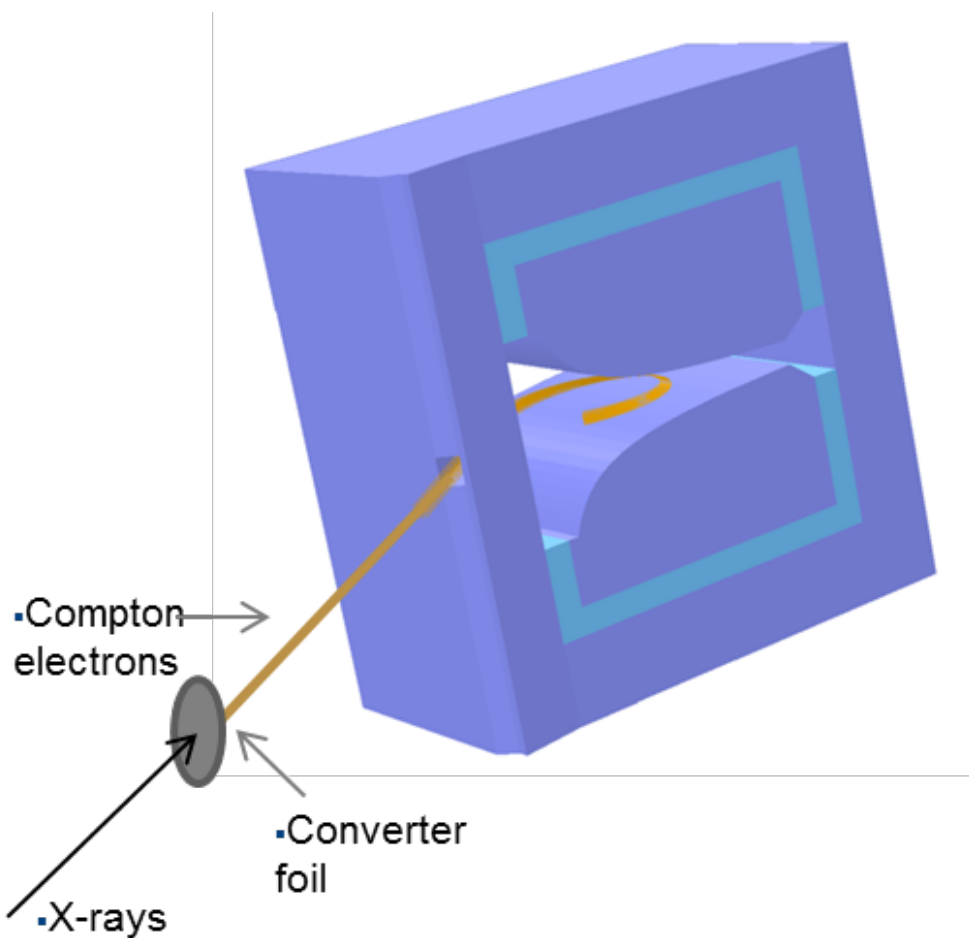


DARHT

550 rad at 1 m; 50 ns pulse



Our Compton spectrometer



Our Compton spectrometer

Interesting features:

- 300 kg neodymium-iron magnet
- 632 G/cm field gradient; maximum field of 12 kG
- Distance electron crosses focal plane proportional to square root of electron momentum.
- Design accommodates a broad range of energies (from ~ 1 MeV/c up to 20 MeV/c)
- Reported electron momentum resolution is the larger of 0.1 MeV/c or 1% of momentum

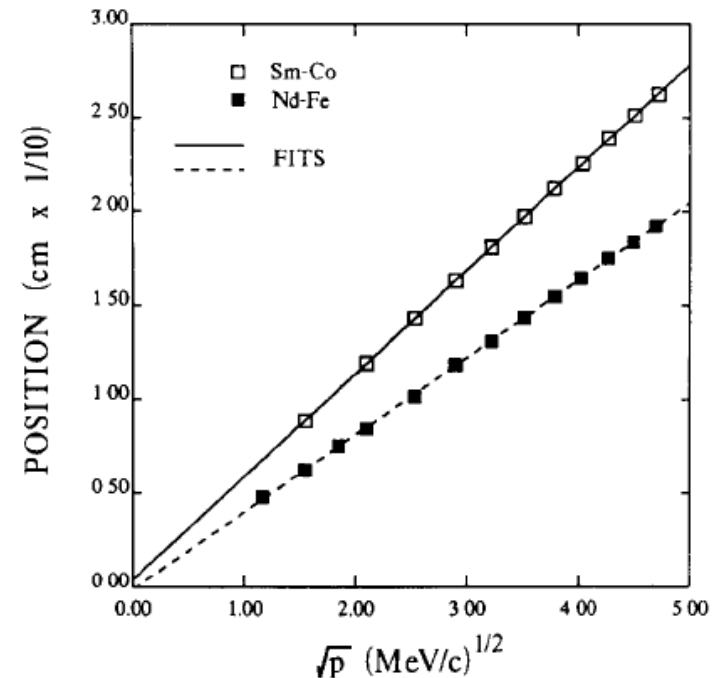


Fig. 13. Measured positions along the focal plane in the two spectrometers versus the square root of momentum. The error bars on the data are smaller than the symbol size. The solid curve is a fit to the data.

Morgan et al., Nucl. Instr. And Meth. A308 (1991) 544

Calibration experiment

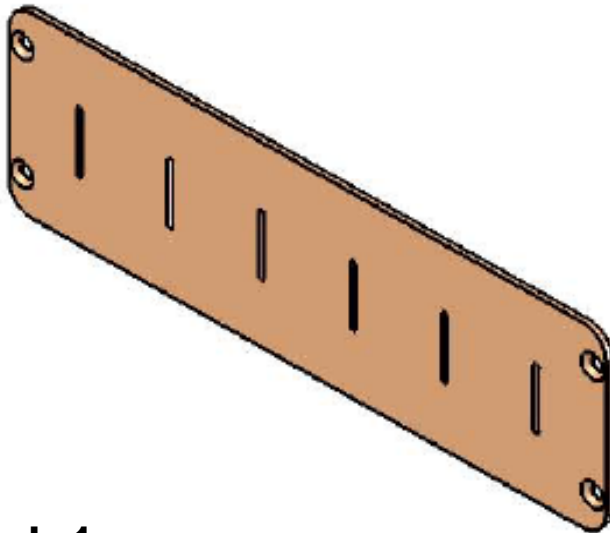
- Conducted July 2014 at the Special Technology Laboratory of National Security Technologies, LLC with a continuous ion beam
- H^- and OH^- accelerated to known energies (1-45 kV)
- 6 brass “button” detectors along focal plane, connected to ammeters
- 2 masks in front of detectors, 16 known positions
- Altered beam energy by varying acceleration voltage
- Relationship between ion momentum and position by design:

$$p \text{ (MeV/cm)} = \frac{Gx^2 \text{ (cm)}}{2 * 3.3356(1 + \sin A)}$$

G = magnetic field gradient in kG/cm

A = entrance angle with respect to focal plane

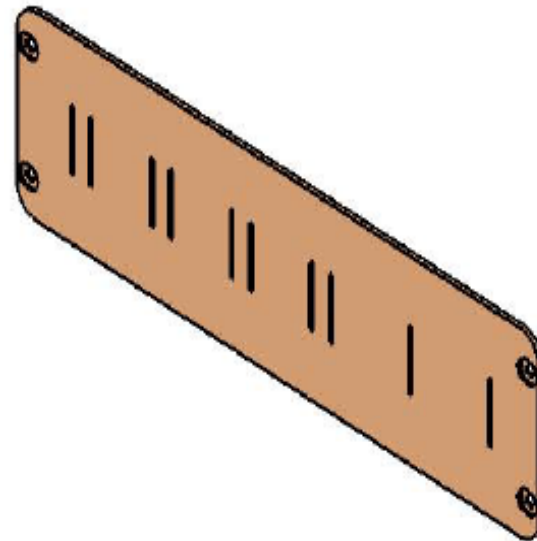
Masks



Mask 1

Slits are centered over the brass detectors

All slits 1.5 mm wide



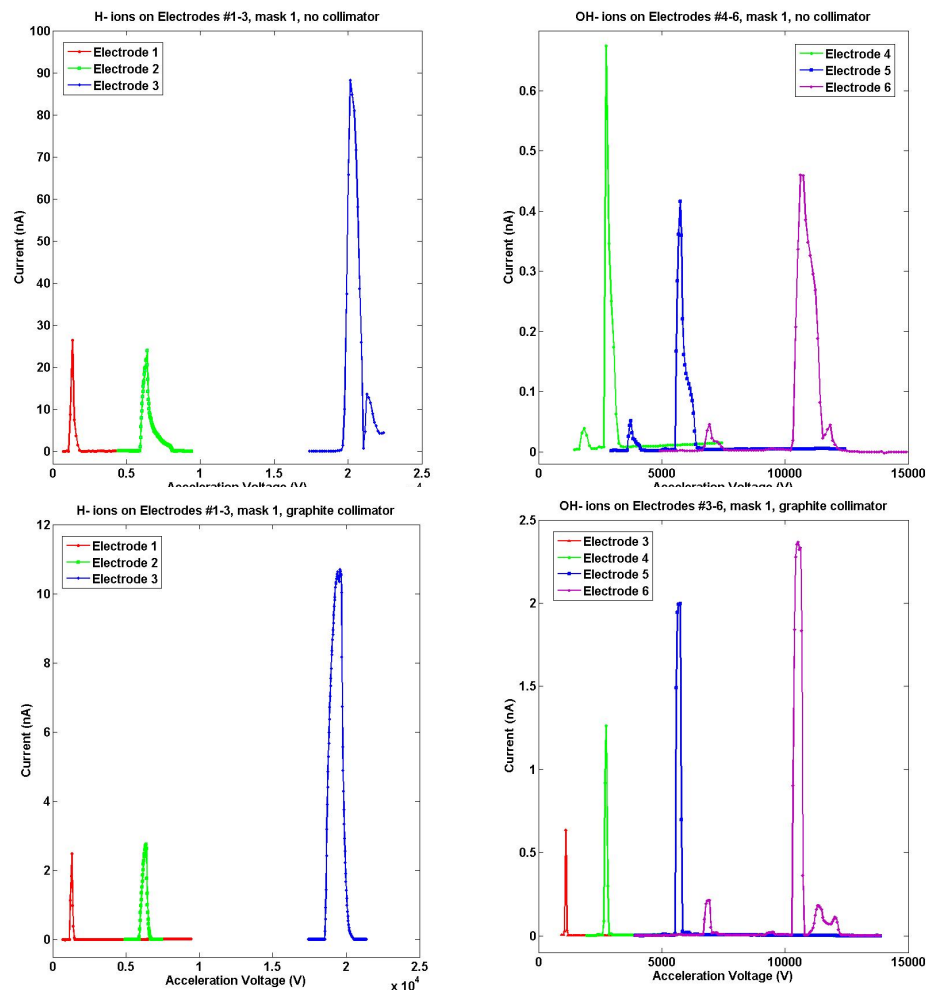
Mask 2

Paired slits -2 mm and +4 mm relative to the central slit of mask 1

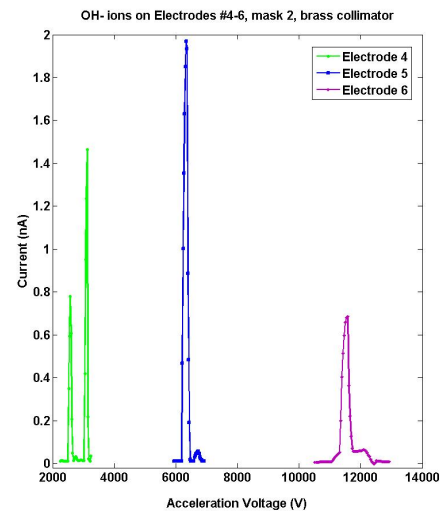
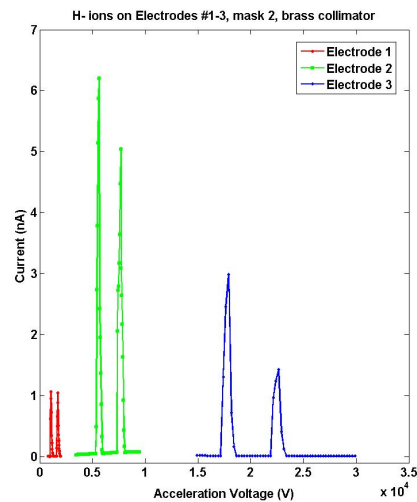
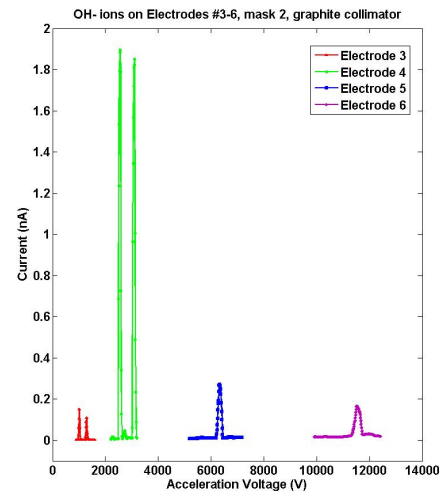
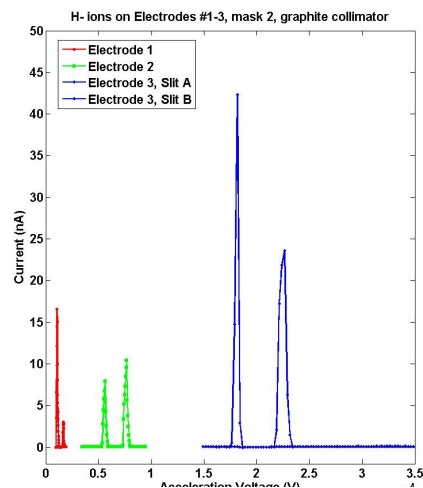
Single slits +4 mm as relative to the central slits of mask 1

All slits 1 mm wide

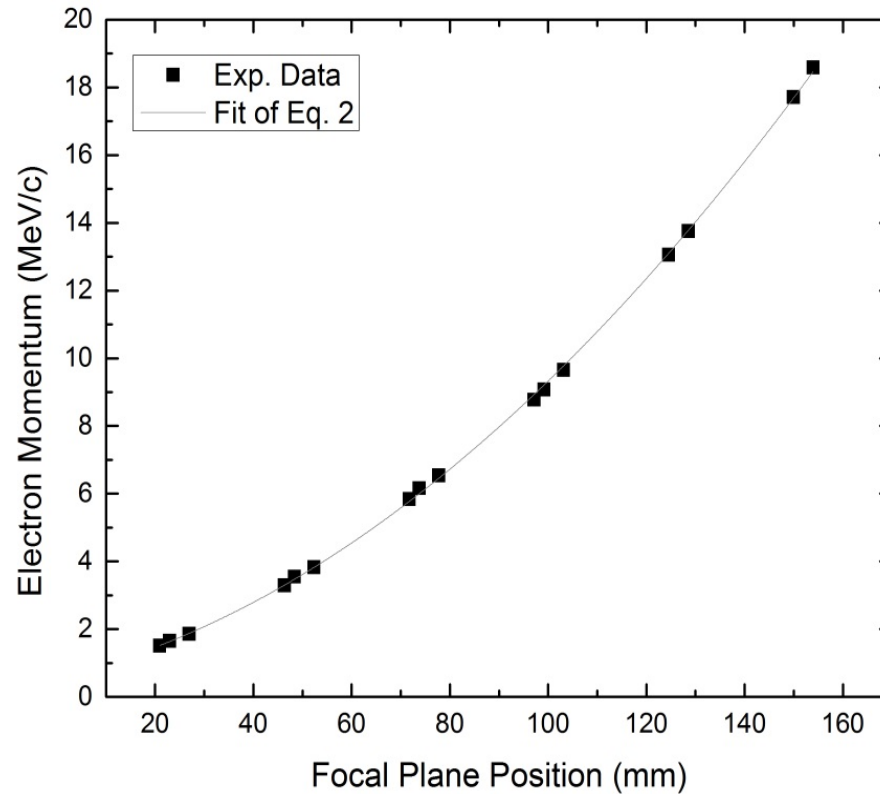
Calibration data – mask 1



Calibration data – mask 2



Calibration results

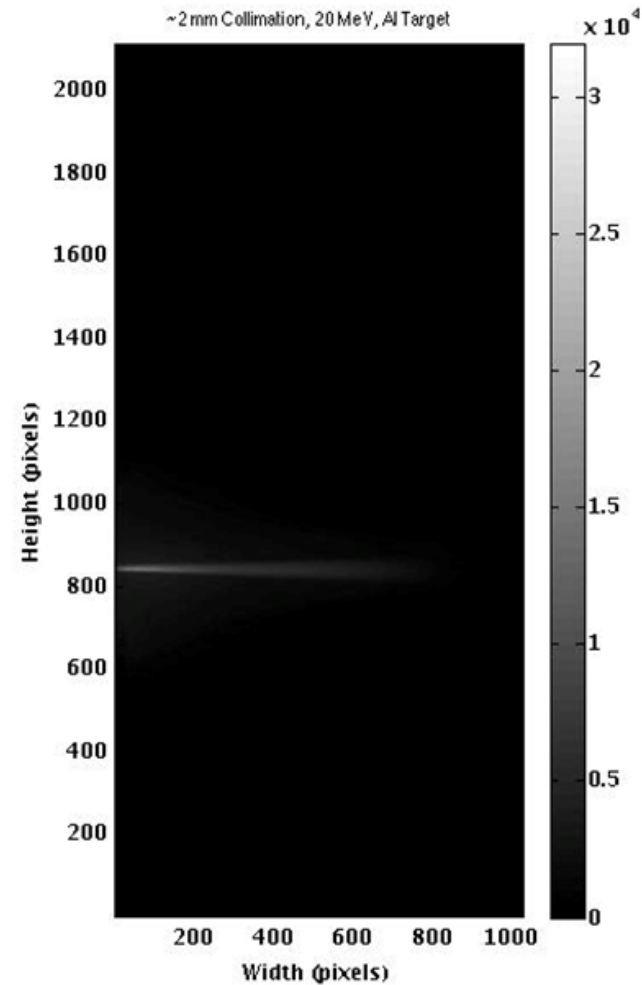
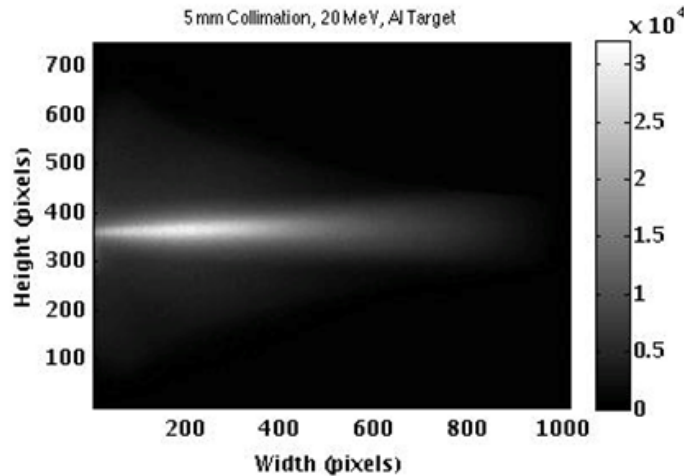


Measurements at the microtron

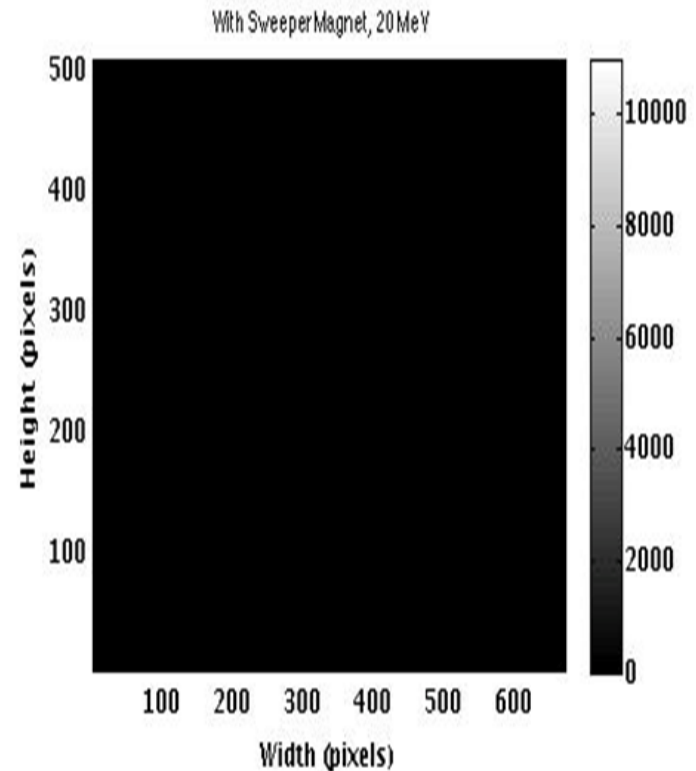
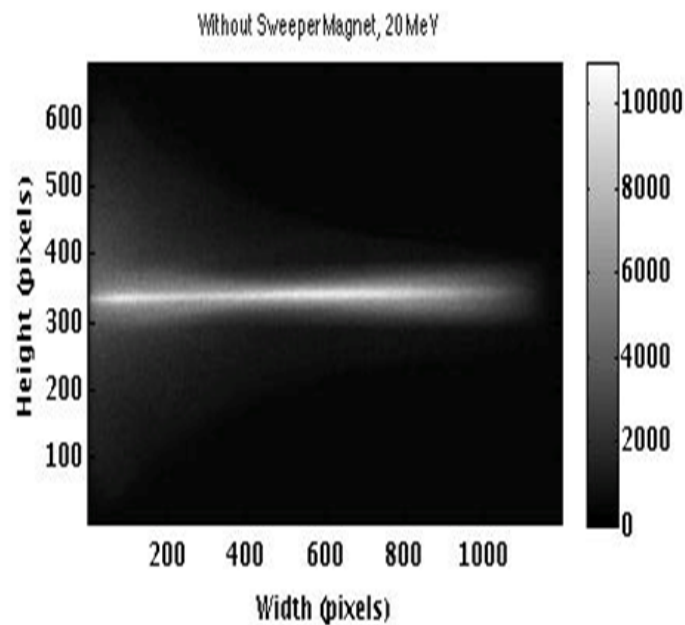
- Bremsstrahlung X-ray source with electron endpoint energies 6, 10, 15, 20 MeV
- 5 mm tungsten collimator, reduced further to ~2 mm
- Sweeper magnet
- Electrons detected with storage phosphor
 - Drop vacuum every energy change
- Graphite collimator for $\sim 1^\circ$ angular acceptance
- Excellent agreement w/ predicted energy endpoints



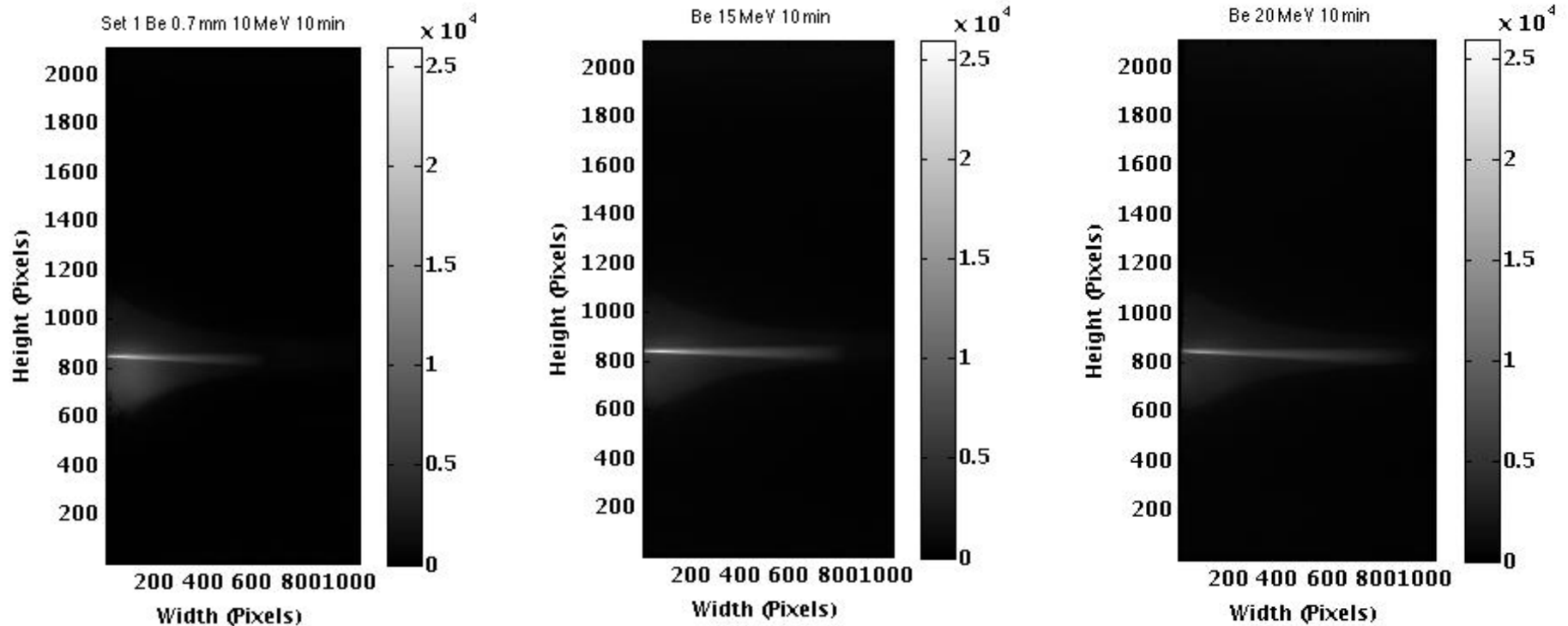
Improved collimation



Addition of sweeper magnet

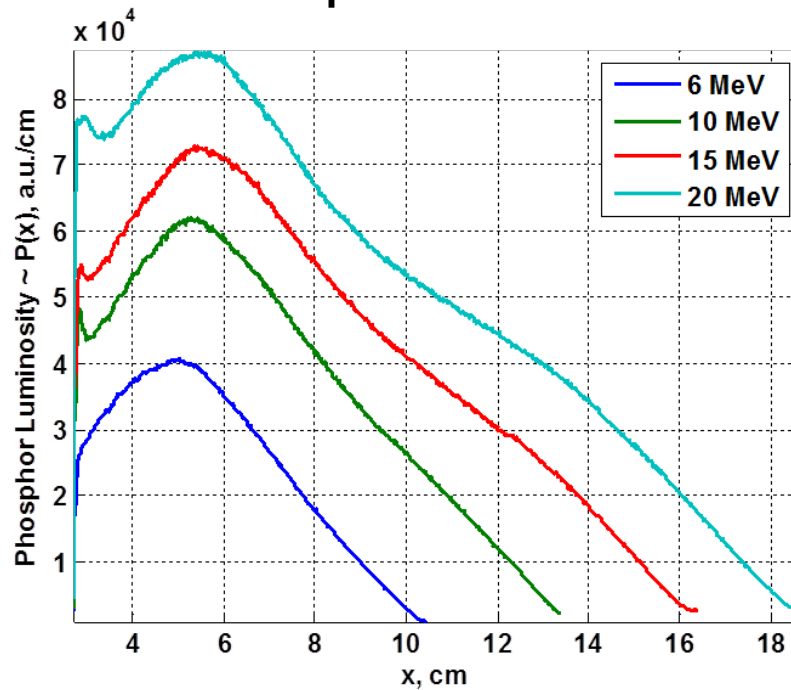


Storage phosphor images

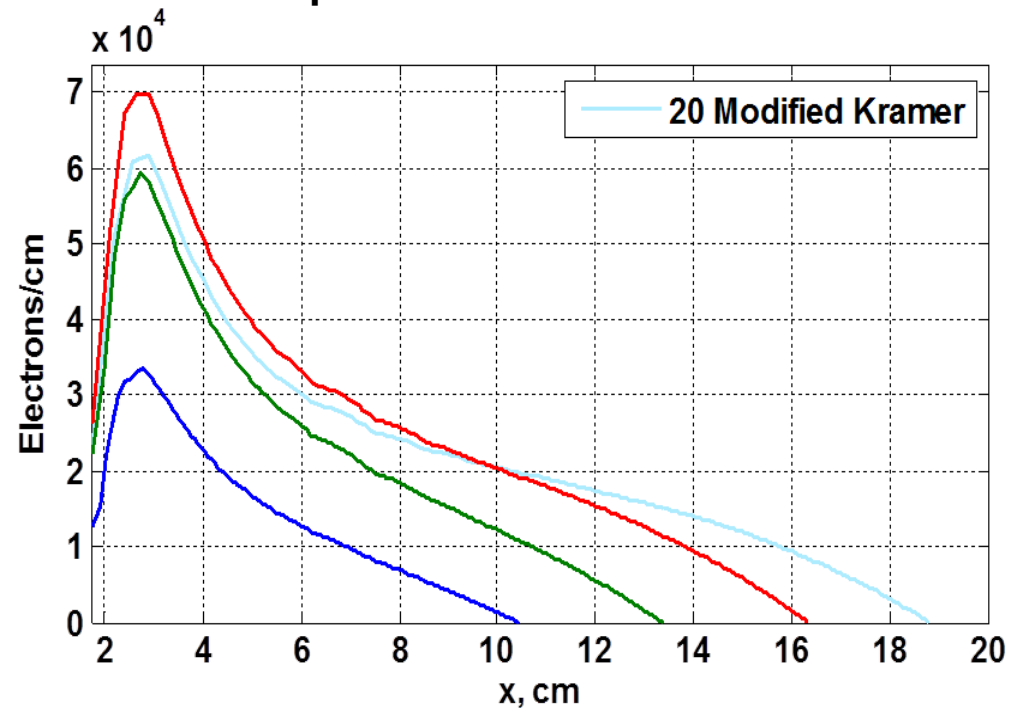


Reconstructed spectra

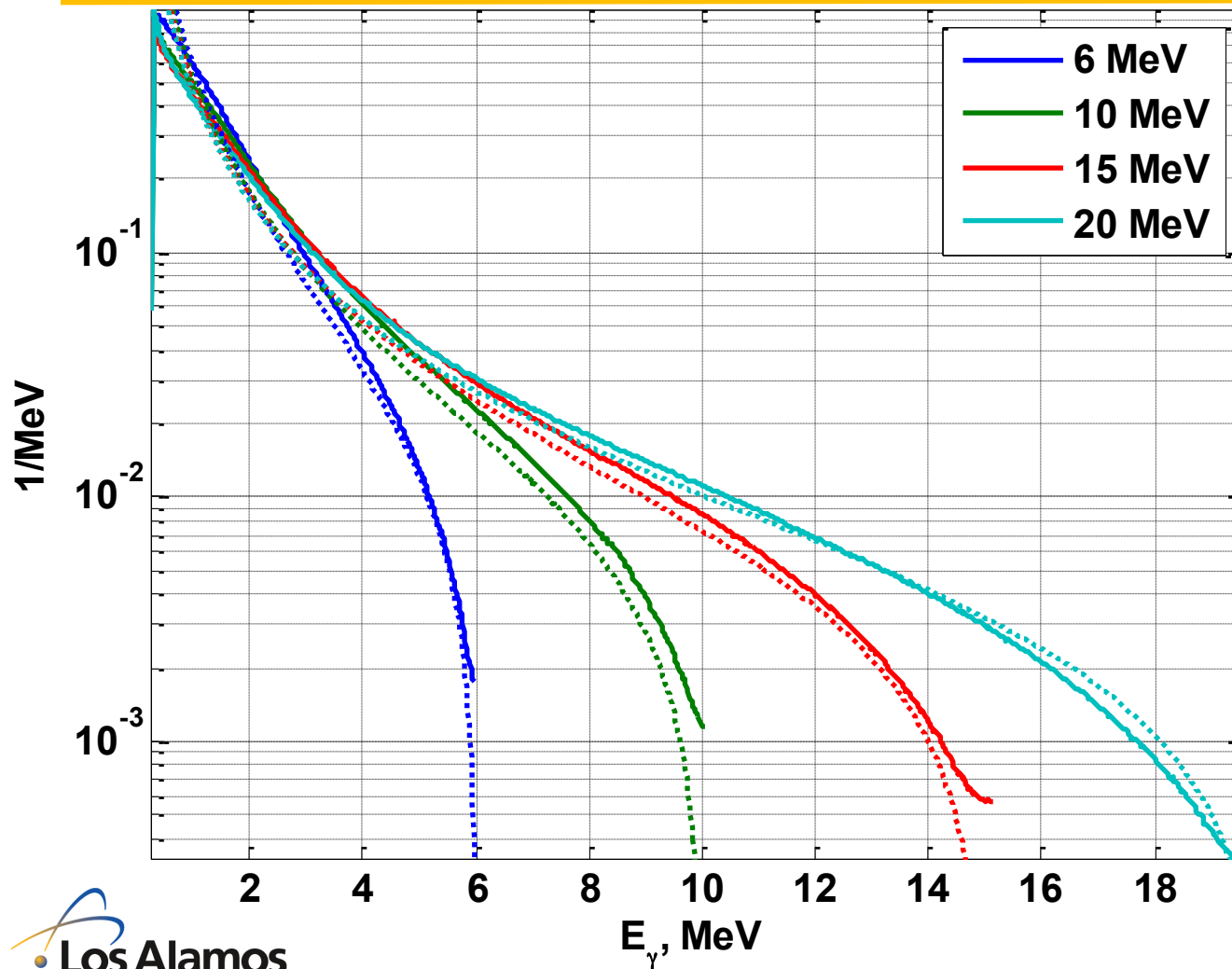
Experimental Data



Model of Expected Electrons/cm vs Position



Reconstructed x-ray spectra

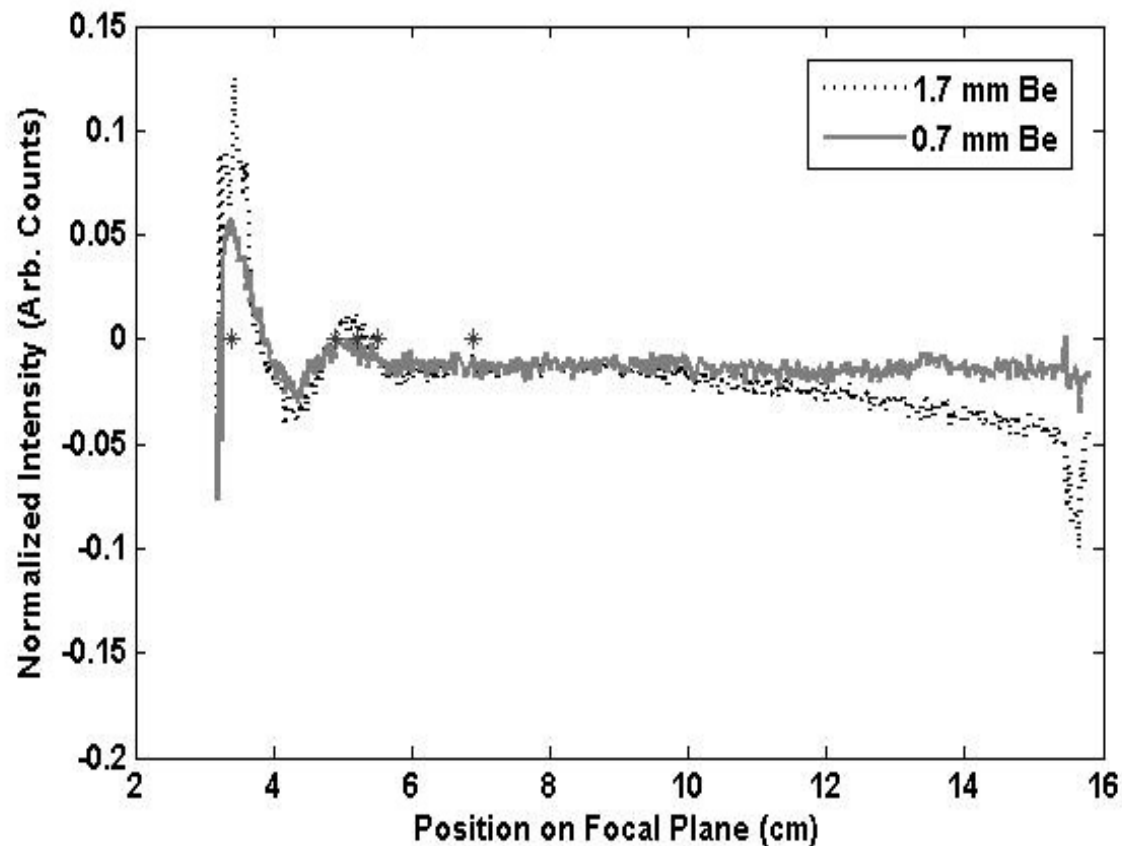


Solid = measured data reconverted to gamma position;
Dashed = Bremsstrahlung model; no correction for background, assumes energy independent response of phosphor

^{60}Co measurements

- 9.5 Ci source
- Varied thickness of beryllium target: 0.5, 1.2, and 1.7 mm
- ~40 rad on target
- Removed graphite collimator to increase acceptance
- Lessons learned
 - Inadequate shielding
 - “Floorshine” contributed to high background
 - Tight collimation required for good resolution

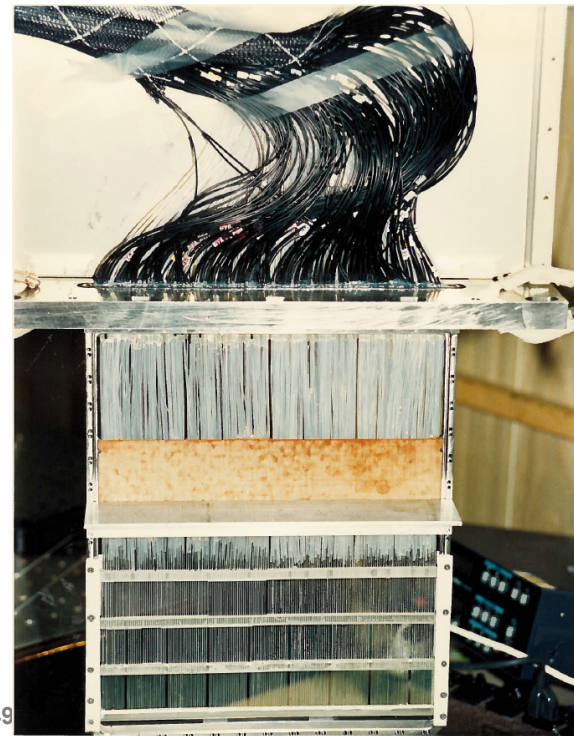
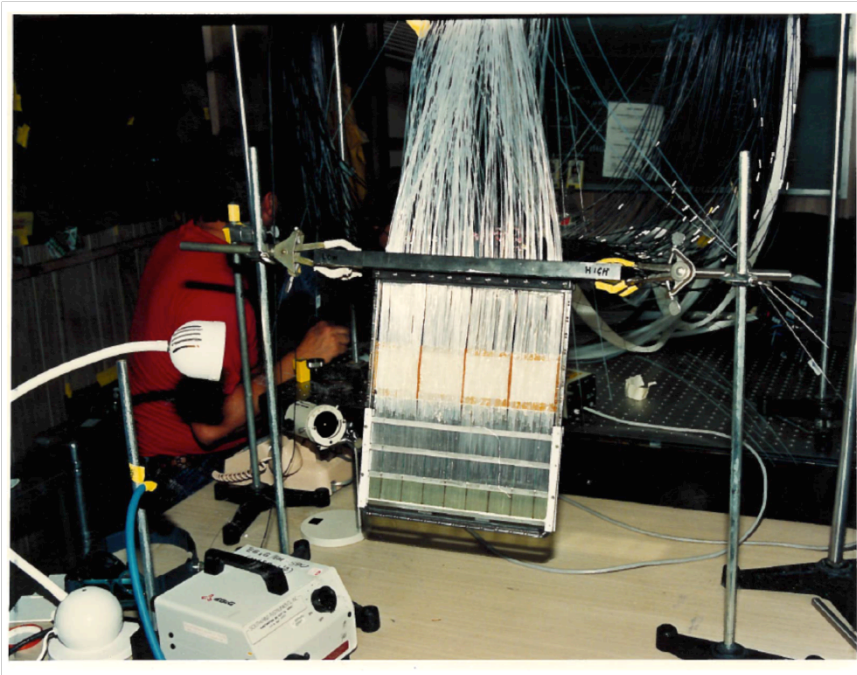
^{60}Co spectrum



* Indicate 0.5, 1.17, 1.25, 1.33, and 2.5 MeV

Future development of detector system

- Time-integrated detector system will be an array of plastic scintillators
- Time-resolved system is being developed
 - Goals: Bin size ≤ 250 keV and ~ 1 ns time resolution



Path forward

- Measure DARHT spectrum by end of calendar year
- Measure RITS-6 spectrum early next year
- Build, test, and calibrate time-resolved detector system
- Determine and test detector system shielding
- In parallel, design and fabricate lower field magnet (or smaller magnet) for lower energy sources
 - Field currently 632 G/cm and electron energy range 1-20 MeV; 100 G/cm would shrink the range to 0.2-3 MeV
- Modify detector system if necessary for low-energy spectrometer
- Possible spectrum measurements at other facilities

Summary

- Experimental procedure was improved (collimation, alignment, etc.)
- Calibration experiment was successfully conducted
- Preliminary reconstructed spectra of microtron and ^{60}Co sources are reasonable

Work in progress

- Analysis of calibration, ^{60}Co , and microtron experiments
- Preparations for RITS-6 and DARHT measurements – including calculations of shielding requirements
- Detector system development

Energy Calibration

- ^{60}Co source at NSTec Source Range – resolve 1.17 and 1.33 MeV lines?
 - Will need to shield spectrometer for the first time
 - 20 MeV High Repetition-Rate LINAC
at Idaho Accelerator Center
 - Will potentially measure 0.5-20 MeV
electrons, 0.5 MeV step
- Morgan et. al.
- Focus on alignment issues

X-rays Compton scatter into easier-to-detect electrons

- Most electrons are forward
- Restricting angular acceptance of Compton electrons, incoming gamma energies & ejected electron momenta are simply related
- Magnet relates energy to position

